Costs of Air Quality Regulation

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Abstract

This paper explores some costs associated with environmental regulation. We focus on regulation pertaining to ground-level ozone (O_3) and its effects on two manufacturing industries — industrial organic chemicals (SIC 2865-9) and miscellaneous plastic products (SIC 308). Both are major emitters of volatile organic compounds (VOC) and nitrogen oxides (NO_x), the chemical precursors to ozone. Using plant-level data from the Census Bureau's Longitudinal Research Database (LRD), we examine the effects of regulation on the timing and magnitudes of investments by firms and on the impact it has had on their operating costs. As an alternative way to assess costs, we also employ plant-level data from the Pollution Abatement Costs and Expenditures (PACE) survey.

Analyses employing average total cost functions reveal that plants' production costs are indeed higher in (heavily-regulated) *non-attainment* areas relative to (less-regulated) *attainment* areas. This is particularly true for younger plants, consistent with the notion that regulation is most burdensome for new (rather than existing) plants. Cost estimates using PACE data generally reveal lower costs. We also find that new heavily-regulated plants start out much larger than less-regulated plants, but then do not invest as much. Among other things, this highlights the substantial fixed costs involved in obtaining expansion permits. We also discuss reasons why plants may restrict their size.

Keywords: environmental regulation; costs; investment; plant size

Introduction

An ongoing debate in the United States concerns the costs environmental regulations impose on industry. In this paper, we explore some of the costs associated with air quality regulation. In particular, we focus on regulation pertaining to ground-level ozone (O_3) and its effects on two industries sensitive to such regulation — industrial organic chemicals (SIC 2865-9) and miscellaneous plastic products (SIC 308). Both of these industries are major emitters of volatile organic compounds (VOC) and nitrogen oxides (NO_x), the chemical precursors to ozone. Using plant-level data from the Census Bureau's Longitudinal Research Database (LRD), we examine the effects this type of regulation has had on the timing and magnitudes of investments by firms in these industries and on the impact it has had on their operating costs. As an alternative way to assess costs, we also employ plant-level data from the Pollution Abatement Costs and Expenditures (PACE) survey.

Our prior work has found a variety of effects on industry behavior attributable to environmental costs (Becker and Henderson, 2000). Here we attempt to quantify some of these costs. To identify effects, we use spatial variation in regulatory stringency as well as temporal differences arising from the introduction of heightened regulation. Our previous research has shown that plant age and plant size are important determinants of *who* gets regulated *when* and *how intensely*, so we incorporate these elements into our analysis here as well. Our models also control for location-specific fixed effects, which is critical in this type of work. Here, we find that regulation indeed significantly increases production costs, especially for young plants, with estimates that (arguably) are higher than what expenditure data from the PACE survey suggest. Our results also show that regulation may lead plants to restrict their size, and reasons for why this might be the case are discussed. We also find that, in at least one of these two industries, investment profiles are significantly altered for plants subject to regulation, with relatively more up-front investment and less phasing-in.

In the next section, we offer a general overview of air quality regulation in the United States, introducing our key environmental variable and discussing some of the difficulties involved in identifying a control and treatment group for empirical work. In the section that follows, we discuss the results from our prior research that led us to our current focus. We then turn to a description of our data. The three ensuing sections present results from our analyses of the size and timing of investments, regulatory costs using data from the LRD, and cost estimates using PACE data. The final section offers some concluding remarks.

The Nature of Air Quality Regulation

Each year (since 1978) each county in the United States is designated as either being in or out of attainment of the National Ambient Air Quality Standards (NAAQS's) for ground-level ozone. Areas that are in *non-attainment* of this standard are, by law, required to bring themselves into *attainment*, or face harsh federal sanctions. The primary way of achieving attainment is through the regulation of VOC- and NO_x-emitting sources within one's jurisdiction – particularly manufacturing plants in certain industries. As a result, these plants in non-attainment areas face much stricter environmental regulation than their counterparts in attainment areas.

For example, in non-attainment areas, plants with the potential to pollute are subject to more stringent and more costly technological requirements on their capital equipment. *New* plants wanting to locate in non-attainment counties (as well as *existing* ones undertaking major expansion and/or renewal) are subject to Lowest Achievable Emission Rates (LAER), requiring the installation of the "cleanest" available equipment without regard to cost. Existing plants in non-attainment counties, who are grandfathered from these strict requirements (at least until they update their equipment), are required to install Reasonably Available Control Technology (RACT), usually some simple retro-fitting, which is to take into account the economic burden it places on a firm. In contrast, in attainment counties, only *new* plants and only those with the potential to emit over (originally) 100 tons per year of a criteria pollutant are subject to any regulation on their capital equipment, and the technological standard is a weaker one. Rather than LAER, large new plants in attainment counties are required to install Best Available Control Technology (BACT), which is negotiated on a case-by-case basis and is to be sensitive to the economic impact on a firm. Existing plants and small new plants in attainment areas face no specific requirements on their capital equipment.

In addition to more stringent technological requirements, non-attainment status also usually entails higher costs in other areas as well. Forced to "produce environmental quality," plants in non-attainment areas must purchase additional inputs. Additional labor is certainly required; however, "environmental production" may also call for more (and/or more expensive) materials and energy as well. Costly redesigns to production processes can also be involved. And any proposed expansion – either the construction of a new plant or the modification of an existing facility – must first be approved by environmental regulators. This permitting process can involve lengthy and costly negotiations over equipment specifications, emission limits, and the like. The purchase of pollution offsets may also be required. Finally, plants in non-attainment areas face a greater likelihood of being inspected and fined than their counterparts in attainment areas.

As this discussion reveals, we have (at least in principle) a control and treatment group with which to estimate the costs of regulation. In particular, given age (i.e., new versus existing plants), we would expect capital costs, labor costs, operating costs, and so forth to be higher for plants in counties classified as being in *non-attainment* of the NAAQS for ozone, than for plants located in counties classified as being in *attainment*. The reality of the situation, however, is a bit murkier than this neat dichotomy would suggest. First, within a county, regulatory scrutiny often varies by plant size. In attainment areas, large new plants are required to install BACT while small new plants have no specific requirements. In non-attainment areas, differential treatment is *de facto* rather than by decree. Local regulators, who are generally resource constrained, focus their enforcement on larger (and hence more polluting) plants while smaller plants have been slow to be classified as polluters, and once classified, may be inspected infrequently or not at all. Then, given plant age and size, regulatory treatment of otherwise similar polluters may differ from one non-attainment area to the next because of variation in state philosophies on how best to achieve attainment. Even within a state, non-attainment areas may face different degrees of regulation because they differ in the *extent* to which they are in non-attainment. Dissimilarities between attainment areas also exist, as some face a degree of regulation above what is normally required of them simply because they are in states with strong environmental agendas.

In the empirical specifications that follow, we are mindful of differences in regulatory treatment that are due to plant characteristics, such as age and size. The remaining differences, then, between attainment and non-attainment areas are *typical* differences, alert to the fact that each group itself may have some significant variation in regulatory intensity. We also note two potential qualifications that affect this interpretation of our results. First, there's the notion that plants in attainment areas may incur environmental costs "voluntarily," as opposed to being *required* to do so by regulators. Such plants, for example, may be reluctant to install "dirty" production equipment in this day and age for fear of protests and law suits, as well as inducing active regulation. Furthermore, for plants in many industries, "dirty" equipment that may still be permissible for use in attainment areas may no longer be available for purchase. Prior to the regulatory era, plants in polluting industries were mostly located in (what would become) non-attainment areas and a considerable proportion still remain there. These producers spur technological innovation and create a market for "green" production equipment that have affected equipment choices for everyone. Therefore, plants in attainment areas may incur 'environmental costs' that are not the result of regulation *per se*, but rather are the result of various other forces (social, political, technological, etc.). Our approach, therefore, of comparing plants in attainment and non-attainment areas, won't reveal the *full* costs of regulation (gotten from comparing a world with regulation to one without regulation *and* these other forces) but should at least reveal a *lower bound* on the costs of regulation.

Our second qualification only serves to lower this lower bound even further. In particular, plants may self-select themselves into attainment or non-attainment areas. For example, it may be the case that firms who choose to locate in non-attainment areas may, to some extent, be those who can best handle regulatory costs. Firms in attainment areas, on the other hand, may be ones for whom regulation would be particularly burdensome. This would suggest that our estimates of regulatory costs are for a select group — *understating* costs for the *typical* plant.[1] Both these qualifications should be kept in mind when interpreting the results below.

[1] In theory, one might control for self-selection by using plant fixed effects in modeling (rather than county fixed effects, which we use here). In practice, however, imposing plant fixed effects eliminates many young plants (since these fixed effects require each plant to appear in two Censuses, at least five years apart), makes identification of age

Prior Findings and Current Motivation

In our previous work in this area (Becker and Henderson, 2000) we investigate the effects ozone non-attainment (versus attainment) status has had on the decisions of firms in polluting industries. In that study (described in more detail below) we focus on major VOC (and NO_x) emitting industries that: (a) have had large numbers of plants and plant births (nationally), and (b) do not have (as) much *other* air pollution emissions. These industries are: industrial organic chemicals (SIC 2865-9), miscellaneous plastic products (SIC 308), metal containers (SIC 3411-2), and wood household furniture (SIC 2511). In this current paper, we focus on just the first two of these. Industrial organic chemicals, as in turns out, is the heaviest polluter of all of these industries (it actually *manufactures* VOCs!) and has the largest average plant sizes. Miscellaneous plastic products uses VOCs in its production and has the convenient property of being the industry with the largest sample size. Plant-level data for both studies come from the 1963-1992 Censuses of Manufactures.

Our current line of research expands upon previous work by Henderson (1996). Prior to this, much of the literature found little effect of state or county differences in environmental regulation on firm behavior (e.g., Bartik (1988), McConnell and Schwab (1990), Gray (1996), Levinson (1996)). Much of this work, however, has been based on cross-sectional data and/or methods, which has proven to be a critical limitation. In order to properly disentangle the inherent locational/productivity advantages typical of non-attainment areas from the adverse (regulatory) impacts of non-attainment status, panel data and methods are necessary, such as those used in Henderson (1996), Becker and Henderson (2000), as well as Kahn (1994). We, again, employ such data and methods here in this paper.

The key findings of our earlier research (Becker and Henderson, 2000) are:

(1) Plant births in these polluting industries (followed by the stocks of plants) have, with the advent of regulation, shifted over time from non-attainment to attainment areas, while general economic activity has not exhibited such a shift. Depending on the industry and time period one looks at, the expected

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effects impossible, and greatly reduces sample sizes. We therefore resign ourselves to any selection bias that may be present, realizing that it will *reduce* our estimates of treatment effects.

number of new plants in these industries in ozone non-attainment areas dropped by 25-45%. The sectors targeted first and most intensely by regulators were those industries with the largest plants and, within industries, the "corporate" sector (with its larger plants) compared to the "non-affiliate" (or single-plant firm) sector. This supports the notion that size matters in *who* is regulated *when* and *how intensely*.

(2) Survival rates of plants in non-attainment areas, while originally the same as those in attainment areas, rose with the advent of regulation. Recall that existing plants are grandfathered from the strictest regulations (until they update or expand their operations) and are only subject to RACT requirements. New plants, on the other hand, are subject to costly LAER requirements. Existing plants, therefore, have a cost advantage over new entrants and reason to stay in business longer than they might have otherwise. Similarly, as regulations tighten over time, former new plants (with former LAER equipment) are exempt from the tightening. The net effect is better survival of existing plants in non-attainment areas and incentive to delay equipment renewal and/or changes in product composition. There is yet another explanation for this result. Older firms may get heavily involved in their states' regulatory process — working with regulators to formulate regulations, advocating for particular laws, and so forth. Even if the regulatory process remains without favoritism, these firms have insiders' knowledge on what their state regulators are most focused on. It may, therefore, be easier and less costly for them to meet the specifications and regulations issued by that particular state.

(3) It appears that plants in non-attainment areas, rather than phasing in investment over a 5-10 year period, do more up-front with less subsequent investment. In terms of sales and employment, we found that new plants in non-attainment areas started off anywhere from 25-70% larger, but after 10 years, no size differences remained. The permitting process for the construction of a new plant in a non-attainment area (as well as the proposed expansion of existing facilities) can require months of costly negotiations – involving the firm, its environmental consultants, state regulators, and the regional EPA – over equipment specifications, emission limits, the purchase of pollution offsets, and the like. By investing all at once, these plants avoid incurring negotiation costs over and over again; moreover, they preserve their grandfathered status.

Our current paper expands upon these findings in two ways. First, we revisit the issue of regulation's impact on the size and timing of plants' investments (in (3) above) by actually examining data on plants' capital stock formation, instead of using sales and employment data as we did before. The questions we ask here (and the methodology we employ) are similar to those in our previous paper. Namely, does non-attainment induce more up-front investment and less subsequent investment as a result of the costly negotiating and permitting process required for plant expansion under regulation? And, given regulatory scrutiny seems to be closely related to plant size, is "downsizing" evident in non-attainment areas relative to attainment areas, once the initial investment period of a new plant is past? Also, how does regulation impact the capital-to-labor usage of plants in these industries?

The second (and major) focus of this paper is in actually quantifying regulatory costs. The birth model estimated in Becker and Henderson (2000) implies that the number of new plants in non-attainment areas drops because the net present value of profits in those areas falls. One view of the birth process is that, in any given year, there is a local supply of potential entrepreneurs to an industry in a county and a (demand) schedule of profit opportunities decreasing in the number of births. Non-attainment status shifts back the (demand) schedule of profit opportunities, moving the county down the supply curve and reducing births. What the implied percentage drop in plant profits (which are unobserved) is is unclear since both demand and supply elasticities are involved in a reduced form specification of birth counts.[2]

In this paper, we look at this issue from the cost side. In particular, we ask what happens to a plant's operating costs if we moved it from an attainment to a non-attainment area. We perform this experiment by comparing the production costs of plants in non-attainment counties (our *treatment* group) with those in attainment counties and those in existence before the advent of regulation (our *control* group). Since our prior work suggests that both plant size and plant age matter in regulation, we incorporate these factors into our analysis as well. And, as we mentioned earlier, this type of work suffers tremendously if inherent county characteristics are not controlled for, so we also employ county

[2] Note that, even with regulation, non-attainment counties do have *some* births, given a local supply of entrepreneurs (with their own idiosyncrasies) and local and regional demand forces.

fixed effects in all our models. Given these fixed effects, the non-attainment effect is identified by differences between attainment and non-attainment counties arising from the imposition of regulation (in 1978), relative to any differences that might have existed in the pre-regulatory period (when there were no *regulatory* differences between these counties). Recalling our comments from the last section, estimated cost differences between attainment and non-attainment areas are likely to represent a lower bound on *true* regulatory costs. We will see in the next section that there are additional reasons why we cannot estimate the full costs of regulation.

The Data

Our plant-level data come from the Longitudinal Research Database (LRD), available through the Census Bureau's Center for Economic Studies. Here, we use only the quinquennial Census of Manufactures from 1972-1992. And, since we require (non-imputed) data on capital assets for both our examination of investment patterns and our estimation of cost functions, we use mainly those plants that are also in the Annual Survey of Manufacturers in those years.[3] We further eliminate any plants that are "administrative record" cases, have their "establishment impute flag" set, or show signs of inactivity (i.e., have a zero value for any critical variable). We further restrict our attention to "corporate" (or "multi-unit") plants. Controlling for age, these plants are much larger than single-plant firms and are therefore more likely to be regulated and exhibit regulatory effects. Their data may also be more accurate than those for single-plant firms, and they certainly account for most of an industry's output.[4] Finally, the inclusion of county fixed effects in our models requires plants to be in counties where at least one other plant-year is observed. The impact of this restriction on sample sizes is relatively slight; less than 5% of plants are lost as a result of this requirement. In the end, our samples contain 70-74% of all multi-unit plants in industrial organic chemicals and 53-61% of all such plants in miscellaneous plastics.

[3] Total assets (buildings and machinery together) was also asked of non-ASM plants in the 1987 and 1992 Censuses. For our cost function exercises, since we are not interested in the separate components of capital stock, we also use these plants in our estimation.

[4] In industrial organic chemicals, corporate plants account for about 97% of the industry's output. In miscellaneous plastic products, they account for about 72%.

In our investment regressions (in the next section) we use a plant's stock of real capital and its real capital-to-labor ratio as dependent variables. For these regressions we use, as our measure of real capital stock, end-of-year machinery and equipment assets (which are on an 'original cost' basis) divided by capital asset deflators constructed from BEA published data (see Becker, 1998). Plant total employment serves as the denominator of our ratio. Here, and in our cost function regressions, plant age dummies are (generally) determined by the time elapsed since the plant's first appearance in the Census of Manufactures, regardless of its industry in that first appearance. In our empirical specifications below, we recognize three separate age categories: 0-4 years, 5-9 years, and 10+ years.[5]

For our cost function regressions, a plant's total costs are defined as the sum of its salaries and wages, its costs of materials, fuels, electricity, and contract work, and the cost of "capital services." The latter is calculated by multiplying beginning-of-year total assets (machinery, equipment, structures, and buildings) by an appropriate "user cost factor".[6] Note that these data from the Census of Manufactures do not subsume all of the (previously noted) costs associated with environmental regulation (e.g., fines, pollution offsets, environmental consultants, etc.), which obviously affects plants in

[5] For example, a plant in the 1972 Census is 0-4 years of age if it is making its first Census appearance in 1972. It is 5-9 years of age if it made its first Census appearance in 1967 and 10+ years of age if it made its first Census appearance in the 1963 Census. The recognition of any additional age categories is not practical. Since the LRD does not contain any of the Censuses prior to 1963, one is not able to distinguish between 1972 plants that are 10-14 and 15+ years of age. Excluding 1972 plants from the analyses (and using just 1977-1992 plants) avoids this problem but unfortunately eliminates an important (control) group of pre-regulatory plants which help us identify the effects of regulation. On the opposite end, *fewer* age categories would not buy us any additional data. In principle, two age categories would allow us to use plants in the 1967 Census as well, however capital asset data were not collected from these plants and therefore they are of no use to us for the types of analyses we wish to conduct here. Three age categories, therefore, is most ideal.

[6] The difficulty here is that that the asset information collected by the Census Bureau is on an 'original cost' basis. It reflects the *book* value of assets (of various vintages and quality and so forth) but not necessarily their true *economic* value. Given the highly imperfect nature of these data, multiplying them by a *proper* user cost of capital series seems somewhat incongruous. What we've done instead is derive "user cost factors" such that capital's share of total costs in our samples (by industry and year) equal capital's share of total output (for the corresponding year and 2-digit industry) in Dale Jorgenson's 35KLEM.DAT (available at his Harvard University website and described in Jorgenson (1990)). For SIC 28 (Chemicals), capital's share of total output in Jorgenson's data ranged from 15.2% (1982) to 21.3% (1987), for the five Census years used in our study. To replicate these shares in our data for industrial organic chemicals required user cost factors ranging from .1495 (1972) to .2136 (1987). For SIC 30 (Rubber and Miscellaneous Plastics), capital's share of total output in Jorgenson's data ranged from 4.1% (1982) to 6.6% (1972). To replicate these shares in our miscellaneous plastic products sample required user cost factors ranging from .0689 (1982) to .0979 (1972). We note that in the initial phases of this study we experimented with time-invariant user cost factors of .17 (e.g., a 10% interest rate plus a 7% depreciation rate) and .10, with results that are remarkably similar to the ones obtained using the factors computed above. We do not believe, therefore, that our results are sensitive to our treatment of the capital data.

non-attainment areas more than those in attainment areas. This is yet another reason to view any estimated cost differences as a lower bound on the true cost of regulation. What *will* be captured here is regulation's impact on the use of labor, capital, and some of the other inputs, as well as any impact it may have on production (output). Here, total output of a plant in a given year is measured by it's total value of shipments in that year, with appropriate adjustments for changes to inventory. This value of output is then divided by the industry's (national) output price index to get a *real* measure of plant output. This price index, along with the industry-specific materials price index (referred to later), is taken from the NBER-CES Manufacturing Industry Database (by Bartelsman, Becker, and Gray).

In addition to these plant-level data, we also have information on county characteristics. In particular, we have LRD-derived, county-level measures of average manufacturing wages and total manufacturing employment, exclusive of the industry being analyzed. We also have county ozone non-attainment status, as recorded annually in the Code of Federal Regulations (Title 40, Part 81, Subsection C). Given 1978 was the first year in which counties were designated as being in or out of attainment, the plants in the 1982 Census of Manufactures would have been the first ones to directly feel the effects of the 1977 amendments to the Clean Air Act. And since previous year's attainment status determines current year's regulation, we use 1981 non-attainment status for 1982 plants, 1986 non-attainment status for 1987 plants, and 1991 non-attainment status for 1992 plants.

The Size and Timing of Investments

The questions we pose in this section are: (1) does regulation induce more up-front investment by plants (versus "phasing-in") as a result of the (fixed) costs involved in capacity expansion, and (2) does regulation ultimately lead to reduced plant sizes, as plants seek to avoid regulatory scrutiny? Regarding the latter, plants could also downsize to reduce investment risk at any one location, in the face of uncertainty over local regulatory costs. In Becker and Henderson (1997), we explore general downsizing issues in these industries. In the miscellaneous plastics industry, we find that plants of the same age are of roughly comparable size across the generations. In the industrial organic chemicals industry, on the other hand, plants built prior to 1968 (i.e., before the 1970 amendments to the Clean

Air Act) are found to be distinctly larger, *at every age*, than plants built after this point (i.e., those who made their first Census appearance in 1972 or later). The size profiles of successive birth cohorts in the regulatory period, however, did not continue to decline. This suggests, of course, that *technological* rather than *regulatory* changes may have led to this "one-time" change in average plant size. But the issue of determining overall trends in plant sizes in this industry is complicated by the fact that there is a great deal of switching of plants into and out of the industry (in comparison to other industries). We find that, after 1972, the number of plants switching out of the industry and the average size of such plants rises quite dramatically, while the sizes of those switching into the industry actually diminishes somewhat. It is difficult, therefore, to come to any firm conclusions.

Here, rather than try to assess the general effects of regulation on plant size, we focus on the differences between attainment and non-attainment counties. Our main interest is in the effects non-attainment status has had on plants' accumulation of real capital stock (machinery and equipment assets in particular), but we also consider possible impacts it may have had on real capital-to-labor usage. We hypothesize that these two items are functions of county characteristics — wages (a cost factor), employment (a scale/demand factor), fixed effects, and ozone non-attainment status — and plant characteristics. In particular, we allow our dependent variables to be functions of plant age (which will allow us to gauge investment patterns over time) as well as age interacted with non-attainment status (which allows us to measure the differential impact of regulation). Results from these regressions are in Table 1.

We clearly see that capital assets rise with plant age. In the industrial organic chemicals industry, relative to the base group (new plants in attainment counties), plants 5-9 years of age are 67% larger, those 10+ years are 97% larger, and those built prior to 1968 are 176% (0.968 + 0.793 = 1.761) larger. In miscellaneous plastics, these percentages are 45%, 81%, and 122%, respectively. The final percentage in each of these trios reinforces the notion (discussed above) that plants built before 1968 (and the 1970 amendments to the Clean Air Act) are simply larger than those constructed later.

What effect does regulation have on these patterns? In industrial organic chemicals, new plants in non-attainment counties are 79% <u>larger</u> than new plants in attainment counties. Plants 10+ years of age, however, are actually 13% smaller in non-attainment counties than similar plants in attainment counties.[7] These results support our hypotheses: regulation induces greater up-front investment in non-attainment counties but tempers the size of mature plants.

The story is different, however, for plants in non-attainment areas built prior to 1968. In industrial organic chemicals, these plants are actually 11% larger than similarly old plants in attainment counties.[8] This suggests an intriguing possibility. These old plants in non-attainment areas have various competitive advantages over new entrants — aspects of their operations are grandfathered; they are experienced players in the local regulatory process, learning long ago how to work with regulators and how to coexist with their neighbors, and so forth. These plants, therefore, may be in a better position to exploit the scale economies inherent in production (see next section), and given grandfathering and an exodus of competitors, they may have access to relatively large regional demands, compared to similar plants in attainment areas. As such, it may be profitable for them to operate on a scale larger than that of their attainment area counterparts who face substantial numbers of new entrants.

Turning to the miscellaneous plastic products industry, our hypotheses are really not born out. In this industry, after controlling for plants built prior to 1968, real capital stocks are no different between plants in attainment and non-attainment areas at different ages. Since total capital investments in this industry are so much smaller than they are in industrial organic chemicals (in any given Census, the average multi-unit miscellaneous plastics plant has about 6-7% of the machinery and equipment assets of the average industrial organic chemicals multi-unit plant) issues of phasing-in and downsizing and so forth may be less relevant here.[9]

We also see no significant effects of non-attainment status on real capital-to-labor usage in these industries. In fact, very few coefficients in either of these two regressions are actually significant. That we find no effect of regulation on capital intensity is somewhat at odds with our later findings with the

[7] $[(1 + 0.968 + 0.794 - 1.046) - (1 + 0.968)] \div (1 + 0.968) = -0.1280$, or roughly 13%.

[8] $[(1 + 0.968 + 0.793 + 0.794 - 1.046 + 0.555) - (1 + 0.968 + 0.793)] \div (1 + 0.968 + 0.793) = 0.1097$, or 11%.

[9] Having said that, an identical regression (not reported here) on a sample that also includes single-unit firms (in addition to these multi-unit plants) reveals some of the hypothesized effects. Namely, new plants in non-attainment areas were found to start with 20% more capital than their counterparts in attainment areas, but after 10 years, there was virtually no difference between the two groups. Why these effects might be found in the single-plant sector and not the multi-plant "corporate" sector is puzzling.

PACE data that show, at least for industrial organic chemicals, capital expenditures relatively more affected than labor costs.

Quantifying Regulatory Costs

In this section, we compare the average total costs of production for plants in non-attainment counties to those in attainment counties. We assume that, in any period, competitive plants face a constrained cost minimization problem. We could formalize regulatory constraints in various ways, but here we will specify a very general constraint. Suppose l, k, and m are inputs of labor, capital, and materials into production; l_R and k_R are inputs of labor and capital associated with regulation (i.e., pollution reduction); w, r, and p_m are the respective factor prices (which are exogenous to the firm), and X is plant output. A plant's constrained cost minimization problem (with respect to l, k, m, l_R, and k_R) could be written as:

$$\begin{aligned} & w\cdot(l + l_R) + r\cdot(k + k_R) + p_m\cdot m \\ & - \theta\{X - X(l, k, m; age)\} - \lambda\{R_h(l, k, m, l_R, k_R; age)\} \end{aligned} \tag{1}$$

Here, the $R_h(\cdot)$ function is the regulatory constraint, where h indexes the two possible regulatory states: attainment and non-attainment. Note that we've allowed plant age to affect both the technology of the plant as well as (and more critically) regulatory stringency. This minimization problem, with its choice of inputs, yields a reduced-form total cost that is a function of factor prices, output, and age. Dividing through by output and invoking linear homogeneity of cost functions, we are left with the following reduced-form *average* total cost function:

$$ATC/p_m = f_h(w/p_m, r/p_m, X, age) \tag{2}$$

We've let our needs and interests dictate our empirical formulation of the equation in (2). Since we're not interested in estimating the elasticities of substitution between factors, a translog specification is too much. And a simple Cobb-Douglas cost function, which is linear in output, is also inappropriate for our purposes. We therefore choose a log-quadratic formulation, which allows for a classic U-shaped average total cost function:

$$(3)\qquad \ln\left(\frac{ATC_{ijt}}{p_{m_t}}\right) = \boldsymbol{a}_0 \cdot \ln\left(\frac{w_{jt}}{p_{m_t}}\right) + \sum_{s=0}^{5} D_{sit} \cdot \left[\boldsymbol{b}_s + \boldsymbol{g}_s \cdot \ln(X_{it}) + \boldsymbol{d}_s \cdot (\ln(X_{it}))^2\right] + d_t + C_j + \boldsymbol{e}_{ijt}$$

where

$D_{0it} = 1$ *for all plants.*

$D_{1it} = 1$ *if plant i is 5-9 years old in year t; zero otherwise.*

$D_{2it} = 1$ *if plant i is 10+ years old in year t; zero otherwise.*

$D_{3it} = 1$ *if plant i is in a non-attainment county in year t; zero otherwise.*

$D_{4it} = 1$ *if plant i is in a non-attainment county and 5-9 years old in year t; zero otherwise.*

$D_{5it} = 1$ *if plant i is in a non-attainment county and 10+ years old in year t; zero otherwise.*

Note that the average total cost of plant i, in county j, at time t, is a function of output, output squared, year effects (d_t), county fixed effects (C_j), and a contemporaneous i.i.d. error term ($\boldsymbol{e}_{ijt}$). Wages (w_{jt}), as we discussed earlier, are average manufacturing wages in the county, exclusive of the industry being analyzed. Since we're not interested in factor price coefficients *per se*, we've taken some liberties with respect to the other two factor prices. We assume perfect capital markets, such that all plants in an industry in a given year face the same price of capital. This, then, is captured by our year effects (d_t). Our material prices (p_m), which come from the NBER-CES Manufacturing Industry Database, vary only over time (within an industry). We can either assume that the price of materials is the same for all plants within an industry within a year or, if one believes that there may be spatial variation in such prices, to the extent that these price differences are constant over time, spatial differences are captured by our county fixed effects (C_j). What we are most interested in here is the shape of the cost curve and how it changes with age and by attainment status. To this end, we've included a series of dummy variables (D_{sit}) which are interacted with the intercept, output, and output squared. These terms allow the shape to differ for six categories of plants (3 age categories * 2 states of regulation).

Results from these regressions are given in Table 2. Note that all the coefficients on the U-shaped structure are statistically significant, with two exceptions in miscellaneous plastics, where the coefficient on nonattainment*output has a t-statistic of 1.584 (significance level of about 11%) and the coefficient on nonattainment*output^2 has a t-statistic of 1.189 (significance level of about 23%). This poses a problem in evaluating results for the plastics industry, which is why we'll focus mostly on industrial organic chemicals in our remaining discussion. In and of themselves, these regression coefficients aren't very interesting. These point estimates, however, are necessary for the exercises that follow.

First, for each industry, we use the estimated coefficients to calculate the level of plant output which minimizes ATC, for each of the six categories of plants. Every situation in each of the two industries happens to be characterized by a U-shaped ATC function (i.e., a negative linear term and a positive quadratic term). For young plants in attainment areas (the "all plant" category) in the industrial organic chemicals industry, for example, the minimum of the average cost curve occurs at $(1.192994 \div (0.0622169 * 2))$, which equals 9.587. (Recall that output and costs are both measured in natural logs.) For industrial organic chemical plants that are 10+ years old and in non-attainment counties, minimum average total cost is achieved at $((1.192994 - 1.078772 - 1.030363 + 1.214576) \div ((0.0622169 - 0.0588917 - 0.0538479 + 0.0632474) * 2))$, which equals 11.727. Table 3 contains the cost-minimizing level of output for *all* categories plants in both industries. We will return to a discussion of these a bit later on.

Next, we take these cost-minimizing levels of output, plug them back into the estimated cost functions, and calculate cost differentials between comparable plants in attainment and non-attainment areas, operating at their respective minimum ATCs. For example, the cost differentials for young plants in the industrial organic chemicals industry is: $[-4.751786 - ((1.192994 - 1.030363) * 9.7162...) + ((0.0622169 - 0.0538479) * (9.7162...)^2)] - [-(1.192994 * 9.5873...) + (0.0622169 * (9.5873...)^2)] = 0.1770$, or 17.7% (given costs and output are in natural logs). Table 4 contains the cost differentials computed for this and all other comparisons. Here (and throughout) differentials will be defined as the percent by which costs in *non-attainment* areas exceed those in *attainment* areas. These are, therefore, expected to be positive.

The results in Table 4 indicate that costs are indeed higher for plants in non-attainment areas, compared to those of similar age in attainment areas. In industrial organic chemicals, young plants in non-attainment areas experience costs 17.7% higher than their counterparts in attainment areas. The difference for older plants, though lower, is still quite considerable, at roughly 10%. This lower cost differential for older plants is consistent with the notion (discussed earlier) that regulatory requirements are stricter for new (rather than existing) plants. In the miscellaneous plastic products industry, production costs are also found to be more expensive for plants in non-attainment counties, but the pattern is the reverse. Young plants in non-attainment areas are found to have costs that are 4.3% higher than their counterparts in attainment areas, while plants 5-9 years of age in non-attainment areas have 8.6% higher costs and plants 10+ years of age have 11.2% higher costs. But again, the precision and accuracy of these estimates are compromised by the two statistically insignificant cost function coefficients used in their calculation. Nonetheless, all these results point in the same direction: non-attainment status leads to higher operating costs for plants in these industries.

A number of issues are raised by our analysis, and we focus on the industrial organic chemicals industry to explore them. First, one may ask why outputs which minimize ATCs might vary by age. As Table 3 reveals, cost-minimizing outputs grow as plants age (though the growth isn't always monotonic). Why do young plants minimize ATC at lower levels of output? It is probably not the case that young plants have technologies that dictate smaller plant sizes. Arguably, some sort of learning process is taking place. Young plants are perhaps best starting off small because they can only handle a simple organizational structure and a smaller scale of operation. As they gain experience, however, and learn more about their local factor (labor and material) markets, they expand. For plants in attainment areas (which show the largest growth in cost-minimizing output!) there is an additional reason for starting out small. Recall that if such plants start out too big, they may be subject to somewhat costly BACT requirements, whereas if they start out small they face no regulation. These small (initially) unregulated plants may then expand as they learn more about their local regulatory environment, and in particular, as they learn from other plants in the area how to best handle (or avoid) regulation. For plants in non-attainment areas, which exhibit smaller changes in cost-minimizing output, there are reasons (discussed previously) for not phasing-in investments this way.

Another issue, revealed in Table 5, is that the output of the "average" plant can be far smaller than the level of output which minimizes ATC. There are a few reasons why this might be. It may be the case that regional goods markets are imperfectly competitive, leading firms to exercise some monopoly power (hence, production shy of cost-minimizing output). Risk avoidance behavior (to reduce exposure) may also lead firms to invest less than what is necessary to minimize average total cost. Having said that, however, we note that the differences between actual and cost-minimizing output in *attainment* areas is absolutely enormous. For plants 5-9 years of age in the industrial organic chemicals industry, the level of output that minimizes ATC (12.46) is about 1.76 standard deviations from the average *ln*(output) of 9.96, and the gap for plants 10+ years of age is even larger! What is limiting the size of these plants? The obvious suggestion is regulation, or more specifically, the threat of regulation. If one believes these particular extrapolations out to the cost-minimizing levels of output, there are (virtually) decreasing average total costs throughout. Plants in attainment areas do not generally grow to these sizes because at some point they *will* attract attention from regulators; they *will* be sued by local interest groups; they may even (single-handedly) pollute their counties into non-attainment. There are, therefore, regulation-related constraints even on these "unregulated" plants (that don't get reflected in production costs). The plants that *do* grow to these sizes may be in lax states, where plants in attainment areas really are left alone — that is, areas that truly are devoid of *effective* regulation.

The oldest category of plants in attainment areas also contain two distinct groups: those built before the regulatory era (say, the 1970 amendments to the Clean Air Act) and those built after. Recall that we acknowledged this distinction (i.e., pre- and post-1968 plants) in our investment regressions above. Attempts to control for this separate group of plants here in our cost functions resulted in coefficients insignificant at the 5% level. However, the coefficients (albeit imprecise as they are) suggested that plants built before 1968 have much larger cost-minimizing levels of output than other plants 10+ years of age. The estimates suggested that those pre-1968 plants could operate at much lower costs in attainment areas if they operated at a large scale — large enough to be regulated, but much less severely than they would be in a non-attainment area. Post-1968 plants that are 10+ years of age, on the other hand, operated at about the same costs in attainment and non-attainment areas. (Differentials for young plants and those 5-9 years of age are unaffected by this re-formulation.) All this might suggest that large pre-1968 plants in attainment areas, as grandfathered players with extensive experience, reap considerable advantages. Having said that, however, it is still the case that very few of these plants operate at even a reasonable fraction of cost-minimizing output. We are, therefore, left with our same conclusion: plants in attainment areas stay small to avoid triggering regulation.

How do differences between the *estimated* cost-minimizing levels of output and the *actual* levels of plant output affect the cost differentials computed in Table 4? To see, we repeated the above exercise using instead average *ln*(output) and *ln*(average output). The results of these (and our previous) computations for the industrial organic chemicals industry are contained in Table 6. The cost differentials for young plants are fairly insensitive to the output measure chosen. Using average *ln*(output), young plants are found to have costs 16.7% higher in non-attainment areas, compared to their counterparts in attainment areas. Using *ln*(average output), this difference was found to be 16.0%. Originally, using ATC-minimizing output, we had found a cost differential of 17.7%. For the older categories of plants, the results are less comparable across output measures. Using average *ln*(output), cost differentials all but disappear for plants over 5 years of age (+1.3% and −1.8%). With *ln*(average output), plants 5-9 years of age are found to have costs 9.0% higher in non-attainment areas (versus 9.9%, using cost-minimizing output), but differences virtually disappear (+0.2%) for plants 10+ years of age. All of these estimates, however, recalling our earlier discussions, are likely to represent *lower bounds* on the true costs of regulation. If nothing else, they uniformly indicate that regulation is most burdensome for new (rather than existing) plants.

An Alternative Approach

Instead of quantifying the costs of regulation by inferring it *indirectly* from a plant's total costs (which we did in the previous section), one could also, in principle, examine *directly* the environmental costs incurred by the plant. The Census Bureau's Pollution Abatement Costs and Expenditure (PACE) survey, for example, asks manufacturing plants about their capital expenditures and operating costs associated with various environmental efforts. This survey, however, has been criticized for potentially missing a large portion of environmental expenses (see Jaffe, *et al*. (1995) for a discussion). It is generally the case that plants do not keep special track of their expenditures on environmental protection. These data therefore must be estimated. Capital expenditures of the "end-of-line" variety (e.g., scrubbers, filters, precipitators, and so forth) are rather straightforward to estimate, since these items are easily identifiable and their sole purpose is pollution abatement. However, when capital expenditures are of the "production process enhancement" type (e.g., the installation of new equipment which improves production efficiency *and* reduces air emissions) the task is much more difficult.

In these instances, survey respondents are asked to "estimate the pollution abatement portion [of such projects] as the extra cost of pollution abatement features in structures and equipment (i.e., your actual spending less what you would have spent without the pollution abatement features built-in)." The Census Bureau (1994) acknowledges that "interviews with survey respondents indicate that estimating such an incremental cost is difficult in many instances" ... if not impossible. In 1992, the following "special instructions" were added to the survey form to help respondents in particularly difficult cases:

> "Do ***not*** include any of the project cost ***unless*** the primary purpose is environmental protection. If the primary purpose of the project is environmental protection, report the whole production process enhancement project expenditure.... ***Caution:*** A project with the primary purpose of improving production efficiency may include pollution abatement features added to meet legal requirements. Since the primary purpose of such a project is still not environmental protection, do not report ***any*** of the production process enhancement."

Given these guidelines, and the last two sentences in particular, it is not clear whether any of the costs of production equipment meeting strict LAER standards, for example, will be attributed to environmental protection and reported in PACE, especially in the absence of an obvious baseline.

Concerns also apply to operating expenses. The salaries and wages of a plant's environmental staff are rather easily accounted for, but what of a production team who spends a small but non-zero amount of time on various "environmental tasks" or of plant management who must also spend a fraction of its time and effort on environmental issues? Do these costs get captured in PACE? Similarly, the cost of "materials, parts, and components that were used as operating supplies for pollution abatement, or used in repair or maintenance of pollution abatement capital assets" might be easy to estimate, but what about the "incremental costs for consumption of environmentally preferable materials and fuels" or the "fuel and power costs for operating pollution abatement equipment"? Surely these are not easy items to calculate, even for the most talented and organized (and patient) of plant staffs. Apart from the potential under-reporting of capital expenditure and operating costs, there are certainly other potential costs that PACE makes no attempt to capture. For example, adverse impacts on plant output, either from the outright stoppage of production (e.g., to install pollution control devices) or through the loss of operational flexibility (to comply with certain regulatory requirements). All these factors argue for the approach we used in the previous section, where environmental costs (and related effects) are subsumed by total plant costs (and output).

Nevertheless, we conducted some rudimentary analysis of our two industries using plant-level data from the 1992 PACE survey linked to 1992 Census of Manufactures (CM) data from the LRD. Only a relatively small sample of manufacturing plants are actually asked to complete the PACE survey in any given year (e.g., approximately 17,000 in 1992), focusing disproportionately on large (and hence older) plants and plants in polluting industries. After eliminating plants with imputed data (in either the PACE, the CM, or both), as well as other suspicious cases, we are left with approximately 15% of all plants in industrial organic chemicals in 1992 and about 4.5% of all plants in miscellaneous plastic products. This is about one-third the industry coverage we had in our above cost function exercises. And young plants, a segment we found to be particularly affected by regulation in our above work, are under-represented here in our PACE-LRD samples. In industrial organic chemicals, only 7% of our sample consists of young plants (compared to 23% of the 1992 population in this industry), and in miscellaneous plastics, 13% are young plants (compared to 35% in the 1992 population). In our above work, using just multi-unit plants from 1972-1992, young plants accounted for 15% and 26% of our samples, respectively, compared to the 16% and 30% in the universes from which they were drawn. These differences in sample sizes and composition, as well as in the time period covered, should be kept in mind when comparing the results here to the ones found above. In particular, an unfortunate consequence of the limited number of young plants we have here is that we are not able to properly distinguish separate age effects in what we do below.

Table 7 contains some basic statistics for our sample of plants. In particular, we present the share of total plant capital expenditures, labor costs, and operating costs (in 1992) directly attributable to air pollution abatement activity. These shares are gotten from comparing PACE and CM responses to questions on capital investments; salaries and wages; and the costs of labor, materials, energy (electricity + fuels), and contract work; respectively. Note that operating costs as defined here (as opposed to what we used above) do not include the costs of "capital services" (essentially because we do not have data on the *stock* of pollution abatement capital equipment). What is perhaps most striking here is that expenditures on air pollution abatement in these industries appears to be fairly low. Air pollution capital expenditures in industrial organic chemicals only accounts for about 6.8% of total capital expenditure in our sample of plants (6.9% based on published totals). In plastics, this number is under 2%. The share of plant labor costs and operating costs accounted for by air pollution concerns in industrial organic chemicals is 1.8% and 0.9%, respectively. In miscellaneous plastics, these shares are negligible.

While the impact of regulation generally appears to be much smaller here than what we were finding before, a direct comparison is not possible given the aforementioned difference in the way operating costs are measured. We therefore instead turn to a comparison of costs between plants in attainment and non-attainment areas, using the three cost measures that we *do* have here. In particular, we run simple OLS regressions where our dependent variable is a plant's ratio of air pollution abatement expenditures (capital investment, labor costs, or operating costs) to total plant expenditures (in those same respective categories). Our explanatory variables include plant output, plant age, a "multi-unit" dummy, and county ozone non-attainment status. The non-attainment coefficients from these regressions are reported in Table 8. Only relative capital expenditure on air pollution abatement in industrial organic chemicals is significantly higher in non-attainment areas than it is in attainment areas, with a difference of almost 4%. All the other non-attainment coefficients are statistically insignificant and very close to zero.

These estimates obviously suggest much lower regulatory costs than what we were finding with our cost function approach in the previous section. This might be evidence of the long-held belief that PACE misses a substantial portion of environmental expenditures. The potential limitations of this survey (noted above) would obviously understate costs much more for plants in non-attainment areas than those in attainment areas, narrowing the estimated gap between the two groups. Our earlier caveats, regarding possible self-selection as well as "voluntary" environmental expenditures, also apply here – serving to narrow this gap even more. And we note again that our results in Table 8 do not (because we really cannot) distinguish regulatory effects by age. Given our previous results, indicating that *young* plants are most affected by regulation, and given that the PACE sample is actually weighted toward *older* plants, differences in cost estimates may also (to some extent) be due to differences in sample composition. That this potentially heavily-affected group is under-represented in PACE obviously also has potential implications for the aggregate statistics published from this survey. The results here are suggestive, but much more work is needed in this area.

Conclusions

This paper examines the effects air quality regulation has had on the size and timing of plant investment in two particular industries, and the cost such regulation poses on firms in these industries. In the industry with high relative average capital assets, we find that new, regulated plants start out much larger than their unregulated counterparts but then do not invest as much, such that after 10 years, capital stocks of regulated plants are in fact smaller. This is consistent with our previous findings and highlights the substantial fixed costs involved in negotiating expansion permits, the benefits of preserving one's "grandfathered" status, and the desire to stay small (or even downsize) in an environment where the amount of regulatory attention is often correlated with plant size. In terms of quantifying the costs of air quality regulation, our basic results show that heavily-regulated plants indeed face higher production costs than their less-regulated counterparts. This is particularly true for younger plants, which is consistent with the notion that regulation is most burdensome for new (rather than existing) plants. "Unregulated" plants, however, also appear to be affected by regulation (or at least the threat of regulation), as we found that they produce at levels far short of the levels that minimize average total costs. This, again, demonstrates the role plant size plays in regulatory efforts.

References

Bartelsman, Eric J., Randy A. Becker, and Wayne B. Gray. *NBER-CES Manufacturing Industry Database*. (Available via the Internet at the NBER website.)

Bartik, Timothy J. 1988. "The Effects of Environmental Regulation on Business Location in the United States," *Growth and Change*, 19(3), 22-44.

Becker, Randy A. 1998. *The Effects of Environmental Regulation on Firm Behavior*. Brown University Ph.D. Thesis.

Becker, Randy A. and J. Vernon Henderson. 2000. "Effects of Air Quality Regulation on Polluting Industries," *Journal of Political Economy*, forthcoming.

—. 1997. "Effects of Air Quality Regulation on Decisions of Firms in Polluting Industries," *NBER Working Paper Series*, 6160.

Gray, Wayne B. 1996. "Does State Environmental Regulation Affect Plant Location?" Clark University mimeo.

Henderson, J. Vernon. 1996. "Effects of Air Quality Regulation," *American Economic Review*, 86(4), 789-813.

Jaffe, Adam B., Steven R. Peterson, Paul R. Portney, and Robert N. Stavins. 1995. "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*, 33(1), 132-163.

Jorgenson, Dale W. 1990. "Productivity and Economic Growth," in *Fifty Years of Economic Measurement*, Ernst R. Berndt and Jack E. Triplett (eds.). NBER Studies in Income and Wealth, vol. 54. Chicago: University of Chicago Press.

Levinson, Arik. 1996. "Environmental Regulation and Manufacturers' Location Choices: Evidence from the Census of Manufactures," *Journal of Public Economics*, 62(1), 5-29.

McConnell, Virginia D. and Robert M. Schwab. 1990. "The Impact of Environmental Regulation on Industry Location Decisions: The Motor Vehicle Industry," *Land Economics*, 66(1), 67-81.

U.S. Bureau of the Census. 1994. *Pollution Abatement Costs and Expenditures, 1992*. Washington, DC: U.S. Government Printing Office.

Table 1

Capital Stocks Under Regulation

	Industrial Organic Chemicals		*Miscellaneous Plastic Products*	
	ln(K)	K/L	*ln*(K)	K/L
age 5-9 years	0.668**	-49.05	0.455**	-7.124
	(0.188)	(35.63)	(0.057)	(7.366)
age 10+ years	0.968**	-103.23**	0.809**	-7.740
	(0.229)	(43.36)	(0.071)	(9.207)
plant built before 19680.793**	8.57	0.406**	7.643	
	(0.202)	(38.30)	(0.069)	(8.891)
non-attainment	0.794**	82.05	0.062	4.665
	(0.267)	(50.52)	(0.088)	(11.355)
* age 5-9 years	-0.587*	-36.07	0.089	-0.182
	(0.324)	(61.40)	(0.098)	(12.696)
* age 10+ years	-1.046**	-79.10	-0.086	-3.055
	(0.317)	(60.03)	(0.099)	(12.781)
* plant built before 1968	0.555**	13.72	0.120	-2.493
	(0.241)	(45.64)	(0.092)	(11.852)
county wages & employment	yes	yes	yes	yes
year & county effects	yes	yes	yes	yes
N (counties)	1730 (220)	1730 (220)	7745 (820)	7745 (820)
Adjusted R^2	0.545	0.369	0.290	0

Standard errors in parentheses. **Significant at 5% level. *Significant at 10% level.

Table 2

Average Total Cost Functions

	Industrial Organic Chemicals	Miscellaneous Plastic Products
ln (output)	-1.193**	-0.319**
	(0.122)	(0.051)
ln (output) squared	0.062**	0.015**
	(0.007)	(0.003)
age 5-9 years	-3.594**	-0.658*
	(1.116)	(0.338)
* ln (output)	0.850**	0.165**
	(0.231)	(0.081)
* ln (output) squared	-0.048**	-0.010**
	(0.012)	(0.005)
age 10+ year	-4.802**	-0.931**
	(0.817)	(0.297)
* ln (output)	1.079**	0.223**
	(0.168)	(0.069)
* ln (output) squared	-0.059**	-0.012**
	(0.009)	(0.004)

Table 2 (continued)

	Industrial Organic Chemicals	Miscellaneous Plastic Products
non-attainment	-4.752**	-0.734**
	(0.998)	(0.367)
* ln (output)	1.030**	0.143
	(0.216)	(0.090)
* ln (output) squared	-0.054**	-0.007
	(0.012)	(0.006)
* age 5-9 years	4.908**	1.282**
	(2.263)	(0.604)
* ln (output)	-1.144**	-0.308**
	(0.462)	(0.143)
* ln (output) squared	0.064**	0.018**
	(0.023)	(0.008)
* age 10+ years	5.625**	1.815**
	(1.252)	(0.487)
* ln (output)	-1.215**	-0.391**
	(0.258)	(0.115)
* ln (output) squared	0.063**	0.021**
	(0.013)	(0.007)
wages, year & county effects	yes	yes
N (counties)	1847 (233)	8878 (881)
Adjusted R^2	0.232	0.231

Standard errors in parentheses. **Significant at 5% level. *Significant at 10% level.

Table 3

Plant Output Which Minimizes ATC
(in natural logs)

Industrial Organic Chemicals

	Attainment areas	Non-attainment areas
Young plants (0-4 years)	9.587	9.716
Plants 5-9 years old	12.459	9.600
Plants 10+ years old	17.175	11.727

Miscellaneous Plastic Products

	Attainment areas	Non-attainment areas
Young plants (0-4 years)	10.425	10.077
Plants 5-9 years old	13.719	9.516
Plants 10+ years old	16.166	10.163

Table 4

Cost Differential Between Plants
(in Non-attainment areas vs. Attainment areas)
Operating at Respective Minimum ATCs

(in percent by which ATC in non-attainment areas exceed that in attainment areas)

	Industrial Organic Chemicals	Miscellaneous Plastic Products
Young plants (0-4 years)	+17.7%	+4.3%
Plants 5-9 years old	+9.9%	+8.6%
Plants 10+ years old	+10.4%	+11.2%

Table 5

Plant Output Which Minimizes ATC,
Average Ln(Output), Ln(Average Output)

Industrial Organic Chemicals

	Attainment areas	Non-attainment areas
Young plants (0-4 years)	9.59, 9.16, 10.20	9.72, 9.28, 10.61
Plants 5-9 years old	12.46, 9.96, 10.94	9.60, 9.63, 10.57
Plants 10+ years old	17.18, 10.75, 11.62	11.73, 10.63, 11.77

Table 6

Cost Differential Between Plants
(in Non-attainment areas vs. Attainment areas)
Operating at Respective Minimum ATCs,
Respective Average Ln (Output),
Respective Ln (Average Output)

(in percent by which ATC in non-attainment areas exceed that in attainment areas)

Industrial Organic Chemicals

	Minimum ATC	Average Ln (Output)	Ln (Average Output)
Young plants (0-4 years)	+17.7%	+16.7%	+16.0%
Plants 5-9 years old	+9.9%	+1.3%	+9.0%
Plants 10+ years old	+10.4%	-1.8%	+0.2%

Table 7

Costs of Air Pollution Abatement
Relative to Total Costs and Expenditures

	Industrial Organic Chemicals	Miscellaneous Plastic Products
Capital expenditures	6.8% (6.9%)	1.9% (1.6%)
Labor costs	1.8%	0.1%
Operating costs	0.9%	0.2%

(Figures in parentheses are based on published totals.)

Table 8

Non-attainment Coefficients
from Regressions of PACE-to-Total Ratio on
Ln(Output), Ln(Age), Multi-Unit Dummy,
and County Non-attainment Status

	Industrial Organic Chemicals	Miscellaneous Plastic Products
Capital expenditures	0.038*	0.006
	(0.021)	(0.004)
Labor costs	-0.001	0.000
	(0.003)	(0.000)
Operating costs	-0.000	0.001
	(0.002)	(0.001)
N	135-141	571-586

Standard errors in parentheses. **Significant at 5% level. *Significant at 10% level.